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GENDER DIFFERENCES IN NONCONTACT ANTERIOR CRUCIATE LIGAMENT INJURIES

Kimberly G. Harmon, MD, and Mary Lloyd Ireland, MD

After the passage of Title IX in 1972, women began competing in organized sports in large numbers. There was concern that women would have significantly higher injury rates than men. For the most part, these fears were unfounded. Sports injury rates between men and women are similar and, in general, seem to be sport-specific rather than gender-specific.[27, 37, 94, 99] There is, however, an increased predisposition (two to eight times) to anterior cruciate ligament (ACL) rupture in women.* There are many theories and much research devoted to explaining why this difference in injury rate exists.

Research has focused on intrinsic and extrinsic factors. Intrinsic factors are those that are individual, physical, and psychosocial.[6] Intrinsic factors include joint laxity, hormonal influences, limb alignment, notch dimensions, and ligament size. The intrinsic causes tend to be more sex-specific and may not be modifiable. Most research into the cause of ACL injuries has been directed toward intrinsic causes. Extrinsic factors are those related to the type of sport, the environmental conditions, the conditioning of the athlete, and the equipment used.[6] Unlike most intrinsic factors, extrinsic factors are potentially controllable or changeable. Extrinsic factors include conditioning, experience, skill, strength, muscle recruitment patterns, and landing techniques. Extrinsic

*References 5, 14, 23, 25, 31, 45, 47, 57, 62, 80, 93, and 98.

From the Departments of Family Medicine and Orthopedics, University of Washington School of Medicine, Seattle, Washington (KGH); and the Kentucky Sports Medicine Clinic, Eastern Kentucky University, Lexington, Kentucky (MLI)

factors are difficult to measure objectively in a functional, sport-specific way, making research in these areas challenging.

This article briefly reviews the epidemiology of ACL injuries and looks at potential contributing factors to the gender difference in ACL injury rate. In addition, prevention strategies and their usefulness are examined. The indications for surgery and outcomes after ACL reconstruction in men and women are reviewed, and ACL graft choice in women is discussed.

EPIDEMIOLOGY

Thousands of ACL reconstructions are performed every year. To date, the most comprehensive data base available has been the National Collegiate Athletic Association (NCAA) injury surveillance system[69]; however, this is composed of varsity college athletes and the data collected may not be representative of the broader population of athletes.

It is unclear whether ACL incidence varies significantly with age or what the peak age for ACL injury is in a particular sport or in either sex. Studies have been complicated by the lack of a common definition of injury rate. Injury rate is calculated by the number of injuries divided by the total time played by all participants. Recording this data is time consuming, not standardized, and not practical for most people participating in sports. Retrospective gathering of this data is limited severely by patient recall. Data for ACL injury rates in high school athletes currently are being collected and should add significantly to the understanding of ACL epidemiology.

INTRINSIC FACTORS

Ligamentous Laxity

Ligamentous laxity is one of the intrinsic factors that has been postulated as contributing to ACL injury. Two questions need to be answered to address this issue: Does increased ligamentous laxity translate to an increased ACL injury rate? Do women have more ligamentous laxity than men?

In 1970, Nicholas found that male football players who had increased *looseness* had a higher incidence of knee ligament rupture.[70] Others agreed that joint laxity determined by similar tests predisposed people to injury.[1, 61] In contrast, further studies using similar maneuvers to test for laxity did not find a correlation between joint laxity and injury rate in athletes.[20, 28, 30, 36, 41, 48, 51, 66] In the only study looking specifically at ACL injuries, Harner concluded that ligamentous laxity was not a factor in athletes who had bilateral ACL ruptures.[36]

These studies are difficult to compare because they use slightly different methods and none have been validated, and the studies have

differing criteria for establishing a diagnosis of looseness. For example, one study may categorize an athlete with three out of five positive tests as *loose*, whereas another may require an athlete to have four out of five positive tests to be considered *loose*. Most of these studies were done on male subjects or did not comment on gender differences in laxity.[28, 51, 66, 70] All the studies that did comment on gender differences in laxity found women to be more lax than men.[20, 30, 52, 56]

Objective quantification of anterior cruciate laxity as measured by anteroposterior (A-P) translation of the tibia can be done reliably with several different instrumented devices; the most common is the KT-1000 Ligament Arthrometer (Med-Metric, San Diego, CA). Using these devices, early studies found no differences in A-P translation between uninjured men and women at rest.[3, 4, 18, 19, 22, 92, 93] Results of later studies, however, contrasted with earlier results.[44, 77, 78] Rozzi found that women basketball and soccer players had more A-P translation than men as measured by the KT-1000.[78] Rosene duplicated this finding in a broader cross section of athletes.[77] Huston also demonstrated that women had more A-P translation than men with relaxed muscles and when actively trying to resist anterior tibial translation.[44] In a study of 100 subjects, Anderson found that women with ACL injuries had more laxity as measured by the KT-1000 than women with normal knees.[4] A-P laxity increases with exercise,[84, 89, 95] and there is concern that static measurements may not represent ligament conditions at the time of injury accurately.

Thus, female athletes seem to be more ligamentously lax than male athletes. The relationship of ligamentous laxity to ACL injury is uncertain. Further studies examining this relationship are warranted.

Hormonal Influences

Ligamentous laxity is influenced by female sex hormones.[21, 34, 38, 58, 59, 96] During the menstrual cycle, the levels of estrogen and progesterone and their ratio to each other change. The level of the hormone relaxin also is believed to contribute to increased ligamentous laxity in pregnant women and is present in nonpregnant women in the luteal phase (Fig. 1).[49, 90] Estrogen and progesterone receptors have been found on the ACL in men and women,[82] and collagen production by fibroblast in the ACL is affected by physiologic levels of estrogen,[59] fueling speculation that ACL injury may occur more readily in women because of female sex hormones.

In a small study of seven women, Heitz showed that ACL laxity was increased at peak levels of estrogen and progesterone when compared with baseline. Hormone levels were determined by radioimmunoassay in this study. He suggested that the changes were caused by estrogen and progesterone levels; however, it is difficult to separate estrogen and progesterone effects because there is a secondary estrogen increase when progesterone levels peak (see Fig. 1).[38] A study by Slauter-

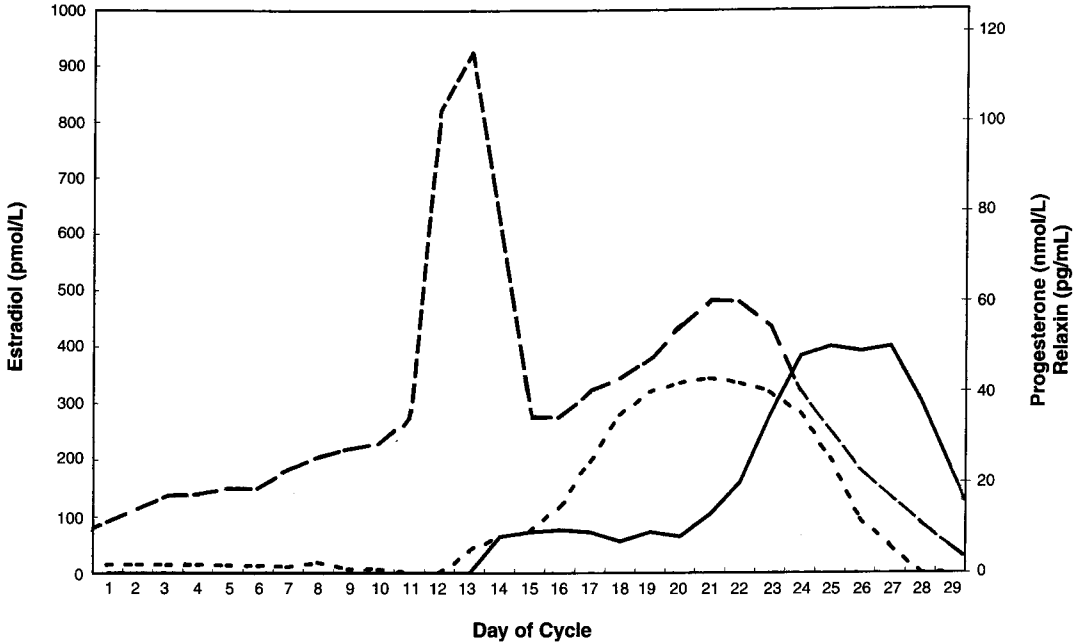

Figure 1. Normal menstrual cycle. Solid line = relaxin; dotted line = progesterone; and dashed line = estradiol.

beck supported a possible contributory role of estrogen in ACL ligament failure. He found that increased levels of serum estrogen decreased failure load of the ACL in rabbits.[85]

The relationship among estrogen, progesterone, and relaxin clouds the picture further. In a study of 21 pregnant women, Schauberger found that joint laxity and A-P translation measured by the KT-1000 increased in pregnancy but did not correlate to serum relaxin levels.[81] Relaxin levels had returned to normal at 2 weeks' postpartum, and ACL laxity had decreased but not to baseline. The delayed return to baseline could represent a delayed or indirect effect of relaxin. Relaxin is undetectable in women during the follicular and ovulatory phase but is present in the luteal phase of a normal menstrual cycle. The levels of relaxin detectable in the normal menstrual cycle are minute compared with those found in pregnancy.[81, 90]

In a study of 28 women, Wojtys reported that ACL injury occurred more frequently during the ovulatory phase of the menstrual cycle (days 10 to 14).[95] The ovulatory phase is preceded by a surge of estrogen and luteinizing hormone. If estrogen is related to increased ACL laxity and decreased ACL strength, this theoretically would be the most likely time for injury to occur. This study was limited in several ways. Five of the subjects in the study were taking oral contraceptives, and their hormone levels would be completely different from naturally cycling women. Women taking oral contraceptives should not be considered in this analysis. Further complicating matters, the cycle lengths of the women studied varied from 21 to 32 days. The menstrual period generally occurs 14 days after ovulation. Difference in cycle lengths usually is caused by increased length of the follicular phase. A woman with a cycle length of 21 days would be expected to have peak estrogen levels around day 7, and in a woman with a cycle length of 32 days, the surge would be anticipated at day 18. Without blood level confirmation of hormone levels or, at the least, women with regular cycles of the same length, accurate conclusions about the relationship of the menstrual cycle to ACL injury are difficult to make.

In contrast to the Wojtys' study, Arendt found the ovulatory phase to be the least likely time of injury.[6] This study had problems similar to those of the Wojtys' study. The phase in the cycle was determined by the patients' memories of their last menstrual periods. It was not documented how soon after injury these women filled out the survey or if the women were relying on memory or menstrual calendars. There were 38 women, 7 of whom were taking oral contraceptives. Of the 31 not taking oral contraceptives, 21 purported to remember the date of their last menstrual period. There was no confirmation of blood hormone levels or correction made for differing cycle lengths, making conclusions tenuous.

In another study using a similar design, it was concluded that there may be an increased risk of ACL injury during the week before the onset or just after the start of the menstrual period.[68] This study relied

on data from 17 women in whom a reliable menstrual history could be obtained.

The complex interplay among hormones and their relationship to ligamentous laxity and ACL injury is not clear. There is no evidence that one point in a menstrual cycle is riskier than another. Studies that have been done suggest different points in the menstrual cycle as the most risky, and are flawed by the problems inherent to retrospective research on ACL injuries and the menstrual cycle and the few subjects. The relative risk of ACL injury at any point in the cycle is still low.

Biomechanical Alignment

Other intrinsic factors are easier to measure. Women have wider pelvises and tend to have more femoral anteversion, larger Q angles, increased external tibial torsion, more overpronation, and an increased thigh–foot angle compared with men (Fig. 2). These all are easily measured variables; however, there are only a few studies that examine alignment and its contribution to ACL injury. Two studies have examined the relationship of Q angle to ACL injury and found no correlation.[31, 43] One of those studies also examined femoral anteversion and found no relationship to ACL injury; however, there was a trend toward increased ACL injury with an increasing thigh–foot angle.[43] Although alignment most certainly contributes to the stresses placed on the ACL, it is difficult to design a good study controlling for so many

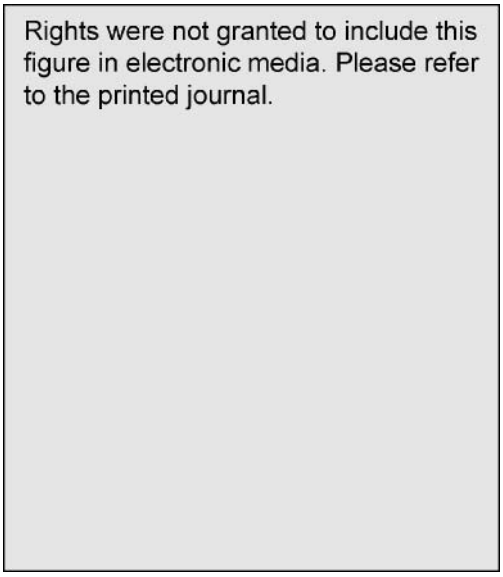

Figure 2. Lower extremity anatomic alignment in females. (*From* Ireland ML: Anterior cruciate ligament injuries in young female athletes: High risks call for new approaches. Your Patient & Fitness. New York, McGraw-Hill 10(5):Sept/Oct, 1996; with permission.)

different variables. Looking at a single variable is simplistic and not representative of all the biomechanics involved. To date, there is no consistent correlation between biomechanical alignment and ACL injury. The relative contribution of each of these variables to ACL injury remains unanswered.

Intercondylar Notch Width

The intercondylar notch is an intrinsic factor that has been well researched. A small notch width index (NWI) has been found to predispose to ACL rupture.[4, 10, 11, 42, 54, 60, 86, 87] NWI is a ratio of the femoral intercondylar notch to the distance between the femoral condyles. The ratio was proposed to compare subjects whose knees were different sizes and to compensate for magnification variability on radiographs.[87] Some studies have found no gender-related differences in NWI,[10, 87, 91, 92] whereas others have shown that there is a difference in NWI between male and female subjects.[67, 83, 86] There is a large range of NWI in men and women and a considerable overlap between genders, making conclusions about the contribution of a small notch to the difference in ACL injury rate between genders questionable.

More recent attention has focused on the size of the ligament in the notch. A small notch may represent a smaller, thinner, weaker ACL, which may be able to withstand less force. Conversely, ACL sizes may be similar, and those that reside in a smaller notch may be impinged or subject to increased forces with rotational stress. In a study of 16 embalmed cadaveric knees, Muneta found that ACLs were similar regardless of sex or NWI.[67] These measurements were taken on Japanese knees with an average age of 74.8 years, and may not be applicable to athletic younger knees or to other races.

Small NWIs, whether representative of increased mechanical loading to the ACL or a physiologically smaller ACL, may contribute to increased ACL injury. Many people with small notches, however, play sports at high levels without injury. There is overlap in NWI between genders and conflicting findings about whether there is a difference in NWI between sexes. Recommendations for prophylactic surgical intervention or restrictions from participation because of a small NWI are premature and inappropriate at this time. There is concern that notchplasty may be only a temporary solution because it remodels with fibrocartilage, leaving a notch no bigger or potentially smaller than the original.[13, 55, 63]

EXTRINSIC FACTORS

Conditioning

Many articles refer to a significantly decreased level of baseline conditioning in women.* As levels of conditioning improve, there is a

*References 2, 5, 16, 17, 33, 44, 45, 53, 64, and 98.

leveling out of injury rates between men and women.[17, 37, 98] The bulk of the literature about conditioning level is related to overall injury rate rather than specifically addressing ACL injury rate; however, many authors have extrapolated this data to ACL injury rate.[5, 12, 45, 64] In a deconditioned athlete, fatigue sets in sooner, which could lead to an increase in injuries by affecting functional joint stabilization.[79]

The only article that specifically addresses the level of conditioning and its relationship to ACL injury cited no difference in conditioning between male and female athletes with ACL injury.[31] This conclusion was observational. Although an overall decrease in the level of conditioning of female athletes is cited as a possible contributing factor to the increased rate of ACL injury in women, there is no good evidence to support the idea that female athletes are less well conditioned than male athletes. Proprioception, preactivation of muscle tension in anticipation of joint loading, and muscle-firing patterns have been shown to change with fatigue in male and female athletes.[79] Whether these changes relate to increased ACL injuries in women or men and whether conditioning programs can forestall ACL injury remain to be answered.

Experience

With the passing of Title IX in 1972, many women began to compete in organized sports with little or no previous experience, which was contrasted with their male counterparts, who typically had many years of athletic experience by the time they entered high school. There was concern that this lack of experience would translate to decreased skill and coordination and increased injury rates. Lack of experience has been proposed to contribute to the increased rate of ACL injury in women.[16, 26, 50]

In 1971, 1 in 27 girls participated in high school sports. In 1998, that figure was 1 in 3.[69a] In 1998, women represented 40% of all high school and college athletic participants.[69a] Opportunities for women have increased over the last 25 years. In the year 2000, with organized sporting opportunities now available for all children, decreased experience in organized sports is less likely to exist.

In a study looking at ACL-injured athletes, there was no difference in the prior organized sporting experience of the male or female athletes.[6] The ACL injury rate in NCAA collegiate male and female basketball and soccer athletes has remained statistically stable over the past decade despite the presumably increased prior experience of the female athletes.[6, 46, 69] Thus, experience, as measured by previous participation in organized sports, does not seem to affect ACL injury rate.

Skill

Skill is another extrinsic factor that has been proposed as an causal factor in ACL injury.[12, 45] Skill is difficult to define and measure objec-

tively. It is the combination of many factors, including conditioning, past experience, coordination, proprioception, neuromuscular control, and mastery and competence in a given sport. Players who are more skilled may play in higher NCAA division levels. When comparing the same gender and sport, there was no difference in ACL injury rates among NCAA division levels I, II, or III.[35] In contrast, there was a higher rate of ACL injuries in men in the more skilled division levels of a soccer league than in men in other division levels.[14] Because skill is not well defined and is difficult to measure, it is more accurate to examine component variables of skill, such as proprioception or muscle activation patterns.

Muscle Strength and Recruitment

Dynamic stabilization of the knee by the hamstring, quadriceps, and gastrocnemius muscles is important in the prevention of ACL injuries. If acting without the protection of dynamic stabilizers, the ACL would fail with the forces of everyday activities.[71, 97] Ratios of hamstring to quadriceps strength were an early focus of research.[29, 75, 88] These studies were limited by conflicting results, differing methods, and the nonphysiologic method of testing and measuring. Muscle activation patterns, using EMG data during functional activities, and studies assessing proprioception, balance, and kinesthesia have been the focus of more recent attention.

Hamstring activation is protective of the ACL.[8, 44, 65, 72, 76] Female athletes rely less on their hamstrings and more on their quadriceps and gastrocnemius muscles than male athletes.[39, 40, 44] Female athletes take more time to develop peak hamstring torque and are weaker in knee extension and flexion strength even when strength is normalized for body weight.[44] They have greater adduction and abduction moments at the knee when landing from a jump than male athletes.[39] These differences in muscle activation and landing techniques between female and male athletes may contribute to the increased proportion of ACL injuries in women. It remains to be answered whether these differences are caused by current training differences in female and male athletes or whether they are a result of innate neuromuscular function.

PREVENTATIVE MEASURES

Not all noncontact ACL injuries can be prevented; however, an impact on injury rates can be made with early instruction in preventative skills: learning how to fall, to jump, and to cut. Plyometric training can reduce landing forces and improve strength ratios,[40] which theoretically could lead to a decrease ACL injury rate. ACL injury prevention programs have been successful.[15, 24, 39] These programs employ strategies that range from increasing hamstring activation and modifying jumping

and landing techniques to increasing awareness of situations potentially risky for the ACL.

Ettlinger described a way to fall in downhill skiing which, when taught by showing videotapes, reduced the risk of serious knee sprains.[24] The study was not randomized, and the group who chose to participate in the study may have been more cautious skiers. The mechanism of knee injury in skiing is different than that in a cutting sport, and these techniques may not be effective in different sports. In a prospective study following 829 women, female athletes not trained in an ACL prevention program had a 3.7 higher knee injury rate compared with trained female athletes and a 4.6 times higher rate compared with the untrained male athletes.[39] Caraffa found a sevenfold reduction in knee injuries in 300 Italian professional and semiprofessional soccer athletes with proprioceptive training compared with an untrained control group of 300[15]; gender was not mentioned in this study.

Intervention programs need to be conducted at many levels, beginning in middle school and continuing through college. The concepts of landing and landing in a safe position should be emphasized. More research is needed regarding the differences in neuromuscular performance between male and female athletes. The defining of muscle weakness on firing patterns that are contributing to all injury may lead to training programs that reduce ACL injuries in female and male athletes. It should also help to develop gender-specific modifications and additions to current training techniques of female athletes.

SURGICAL RECONSTRUCTION

Gender Comparisons After Reconstruction

Few studies have been published comparing outcomes of ACL surgery on the basis of gender. In a comparison of male and female patients undergoing autogenous ipsilateral central bone patellar tendon bone ACL reconstructions, Barber-Westin found similar results on the Cincinnati knee rating scale. At 26 months postoperatively, in 94 patients (47 men and 47 women), there was no difference in complications.[7] The failure rate was 6% in female patients and 4% in male patients. Men and women did equally well after reconstruction; the only significant difference in this study was that the women required an average of six more rehabilitation visits than the men.[7]

It is Dr Ireland's opinion that the female athlete who is ligament dominant is at more risk for associated articular cartilage and meniscal involvement. She should undergo ACL reconstruction if competing in high-risk sports. Because of the physiologic rotatory laxity, when the ACL is injured, there is more instability and potential for osteochondral fracture and meniscus tear. The patient's desired activity level and potential for further injury, not gender, should be the overriding concern determining whether or not reconstruction is undertaken.

Graft Choice

The decision of graft choice is not as critical as the readiness of the patient and knee for surgery—for restoration of range of motion, neuromuscular control, and minimal effusion. The skill and training of the surgeon is of utmost importance. The graft choice is what works best in each individual surgeon's hands. In Dr. Ireland's opinion, the concern about hamstring reconstructions in the female athlete is the fixation and potentially increased laxity compared with patellar tendon autographs.[9, 10, 74]

In a study comparing 46 women with semitendinosis grafts to 97 with patellar tendon grafts, Barrett found a trend toward increased laxity in the hamstring reconstructions.[10] Although KT-1000 measurements were not significantly different, there were more women in the hamstrings group who had knee examinations reported as a +1 Lachman on follow-up. It was not stated whether the same physician performed the surgeries or the follow-up examination. The hamstring group had not returned to their preinjury activity level at 18 months in contrast to the patellar tendon group. In a study comparing the same group of hamstring-reconstructed women with men with hamstring reconstructions, it was noted that the women had more laxity, reported higher intensity of knee pain, and did not return to their preinjury activity level.[9]

Pinczewski compared outcomes of 90 quadruple hamstrings with 90 bone patellar tendon bone autografts. The women tended to have greater laxity in the hamstring groups as compared with the bone patellar tendon bone, although kneeling pain was more common in the patellar tendon group.[74]

Oates looked at injury rates in normal, ACL-deficient, and reconstructed knees in a skiing population.[73] These were elite skiers who were employed in the skiing industry. KT-1000 measurements were similar between the graft types; however, all of those who reruptured their ACL grafts had hamstring reconstructions. Gender was not addressed.

In the female athlete, the ACL should be reconstructed and the joint should be stabilized. Future studies are needed to compare the outcomes after ACL surgery, attempting to clarify whether there are superior graft choices for different genders, ages, or sports.

HUNT VALLEY CONSENSUS SYMPOSIUM

In June 1999, a consensus conference was held in Hunt Valley, Maryland. A panel of experts on ACL injuries met to discuss what was known about ACL injuries, prevention strategies, and directions for further research. The following is a summary of their findings:[32]

Anatomic Risk Factors

- No consensus on the notch's role in ACL injury can be reached.
- There are insufficient data to relate lower extremity alignment to ACL injury.

Environmental Factors

- Shoe-surface coefficient of friction may improve performance but may increase the risk of injury. Because this is a modifiable risk factor, more research should be done in this area.
- There is no evidence that knee braces prevent ACL injury.

Hormonal Influences

- There is no consensus that specific sex hormones play a role in the increased incidence of ACL injuries in women.
- Hormonal intervention or participation restriction is not justified for ACL prevention at this time.

Biomechanical Factors

- The knee is one part of a kinetic chain, and anatomic sites other than the knee—including the trunk, hip, and ankle—may contribute to ACL injuries.
- Neuromuscular factors are significant and may be the most important reason for the increased risk of ACL injuries in women.
- Strong quadriceps activation during eccentric contraction is a major factor in ACL injury.

Prevention Strategies

- Training programs, which enhance body control, reduce ACL injury rates in female athletes and may increase performance.
- Male and female athletes in the same sport may need different training and conditioning programs.

SUMMARY

Female athletes have an increased incidence of ACL rupture. The cause of this increased injury rate is unclear, but it is most likely from a complex interplay between multiple variables. The relative risk of incurring an ACL injury is still low. The increased risk of ACL injury in women compared with men should not discourage female participation in sports. Instead, the focus should be on strategies to prevent injuries. Intrinsic factors are difficult or impossible to change; modifiable risk factors need to identified and prevention strategies should be employed.

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Address reprint requests to
Kimberly G. Harmon, MD
Sports Medicine Clinic
Hall Health Primary Care Center
Box 354110
University of Washington
Seattle, WA 98195–4410